Review Paper

Temperature and COVID-19 Incidence: An Ecologic Study

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ABSTRACT

Background: According to the hypothesis, COVID-19 is less prevalent in regions with warm climates. Contradictory results have led us to investigate the correlation between temperature and the cumulative COVID-19 incidence rate.

Methods: We obtained COVID-19 data from CRONALAB, COVID-DASHBOARD, and MCMC databases of Fars Province, Iran, linked the data and finalized daily COVID-19 cases. The daily data on the temperature was gotten from meteorological stations' reports from March 21, 2020, to March 21, 2021, for each county of Fars Province, Southern Iran. The daily weighted cumulative incidence rate of COVID-19 cases was calculated for all counties, separately. Initially, for uniform data visualization, the average air temperature data were transformed into ranked percentiles. Then, to visually assess the study hypothesis, the distribution of COVID-19 cumulative incidence was visualized on percentiles of temperature. Given the non-linear distribution of the data, we performed exploratory analyses using the generalized additive models and locally weighted (polynomial) regressions to choose the best response function. Then, the generalized linear models were used to parametrically build the model.

Results: The generalized additive models showed a small decreasing, near horizontal, linear pattern for COVID-19 incidence rate as the function of temperature (pseudo R^2: 0.001, deviance explained: 0.13%, coefficient: -0.02). The GLMs showed head-to-head results (deviance explained: 0.13%, coefficient: -0.02], supported by similar Akaike information criteria (AICs) (34945). However, according to the locally weighted regressions model's curve, lower COVID-19 incidence rates were recorded on days when the temperatures ranged from 60 to 80 percentiles, equal to 20°C to 25°C in a cold climate and 25°C to 35°C in a warm climate. This is while the rates increased at lower and upper temperatures.

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Conclusion: Daily COVID-19 incidence rate cannot be explained as a function of daily temperature in Southern parts of Iran. Higher rates of disease transmission out of the range of 20°C to 25°C for cold temperatures and 25°C to 35°C for warm climates might be linked to people's indoor gatherings, coupled with insufficient ventilation.

Keywords: COVID-19, Climate, Temperature, Ventilation

1. Introduction

After the emergence of the COVID-19 outbreak in Wuhan, China in late December 2019, the virus quickly spread throughout China and worldwide. The World Health Organization (WHO) declared a state pandemic on March 11, 2020 [1]. As of September 13, 2021, COVID-19 infected 225 488 186 individuals and caused 4 644 371 deaths, worldwide [2]. In the early months of the COVID-19 pandemic, it was hypothesized that the disease is less prevalent in countries closer to the equator, where heat and humidity are higher. Accordingly, the incidence rate was expected to decline in the summer; therefore, many people and policymakers hoped for the elimination of the disease by the arrival of spring and summer [3, 4]. A study in China reported that 60% of the confirmed cases of COVID-19 occurred in places with temperatures ranging from 5°C to 15°C [5]. Another study in countries closer to the equator suggested that the number of COVID-19 cases has increased [6]. Kassem showed an inverse relationship between the transmission of COVID-19 and temperature; accordingly, as the temperature increases, the number of cases decreases and vice versa [7]. Sobur et al. showed no association between temperature and COVID-19 cases as the daily average temperature was not related to the incidence of COVID-19 [1]. A study that included 144 geopolitical regions worldwide, except for China, South Korea, Iran, and Italy, showed no correlation between the increase in latitude and temperature and the escalation in the COVID-19 pandemic situation [8]. In the south of Iran, an investigation showed that high temperature does not affect the pandemic [9]. Moreover, Jahangiri et al. reported a linear relationship with confirmed COVID-19 in different provinces of Iran; however, the transmission was not extremely sensitive to the temperature. That is, no evidence existed to maintain that confirmed cases of COVID-19 are lower in warmer climates compared to cold weather [10]. Nevertheless, this hypothesis is not confirmed so far and contradictory results have led us to assess the correlation between temperature and COVID-19 incidence rate.

2. Methods

We collected data on COVID-19 from CRONALAB, COVID-DASHBOARD, and MCMC (medical care monitoring center) databases of Fars Province, Iran, linked data, and completed daily COVID-19 cases. The daily data on the temperature, including the minimum, maximum, and average air temperature was obtained from the reports by meteorological stations' from March 21, 2020, to March 21, 2021, for each county of Fars Province, Iran. The data on temperature were recorded for all days without any missing data. Then, the daily weighted cumulative incidence rate of COVID-19 cases (per 100 000) was calculated for all of the counties, separately.

Initially, the average air temperature data were transformed into ranked percentiles for uniform data visualization. Then, to visually assess the study hypothesis, the distribution of COVID-19 cumulative incidence was visualized on percentiles of temperature. Because of the nonlinear distribution of the data, we performed exploratory analyses using the 2 nonparametric regressions, namely the Generalized Additive Models (GAMs) and locally weighted (polynomial) regressions (LWRs), along with a smoothing function to choose the best response function (i.e., linear, quadratic, etc.) Then, the Generalized Linear Models (GLMs) were used to parametrically build the model. The pseudo R^2 deviance explained percentages and coefficients were reported for the regressor (temperature). In addition, the Akaike Information Criteria (AICs) were used to compare the models' goodness of fit. These analyses were performed using "loess," "gam," and "glm" functions, respectively, implemented in the R programming language (version 4.0.4 for MacOS) packages.

This study was reviewed and approved by the Research Review Board of the Ethics Committee of Shiraz University of Medical Sciences (Code: IR.SUMS.REC.1399.174).

3. Results

Fars Province is located in the south of Iran, has the geographical coordinates of 29° 37′ 30″ N and 52° 31′ 54″ E [11], includes 36 counties, and "Shiraz" is its capital [12]. The northern counties have cold climates and the southern areas are warm. The daily air temperature is widely ranged from the lowest temperature of -11°C in Abadeh County to the highest temperature of +50°C in Lamerd County. Counties are classified into the following 3 groups: 1) cold climate in winter, 2) warm climate in summer, and 3) temperate climate. Counties with temperate climates were excluded from this study (Figure 1). The data of the first two groups were included, combined, transformed into the ranked percentiles, and surveyed for the correlation between temperature and COVID-19 incidence rate.

GAMs showed a small decreasing, near to horizontal, linear pattern for COVID-19 incidence rate as the function of temperature (pseudo R^2=0.001, deviance explained=0.13%, coefficient=-0.02) (Figure 2B). The GLMs showed head-to-head results (deviance explained = 0.13%, coefficient = -0.02), supported by similar AICs (34945) (Figure 2C). However, according to the LWRs model's curve, lower COVID-19 cumulative incidence rates were recorded on days with temperatures ranging from 60 to 80 percentiles, equal to 20°C to 25°C in a cold climate and 30°C to 35°C in a warm climate. This is while the rates were increased at lower and upper temperatures (Figure 2A).

4. Discussion

According to the findings, in southern Iran, lower rates of cumulative incidence of COVID-19 were recorded at 20°C to 25°C and 25°C to 35°C for counties with cold and warm climates, respectively, whereas, outside this ranges, the number of cases was increased. However, the daily COVID-19 cumulative incidence rate was not explained as a function of daily temperature. Huang et al. reported that 60.0% of COVID-19 confirmed cases were detected in locations where the air temperature ranged from 5°C to 15°C and had a pick of 11°C. However, they detected few confirmed cases living in regions with temperatures lower than 0°C and greater than 30°C [5]. Another study showed that each 1-degree increase in latitude could be attributed to a 4.3% growth in cases per 1 000 000 [6]. Another study that was conducted using data from 43 countries and 4 time periods showed an inverse relationship between the transmission of COVID-19 and temperature [7]. Mandal and Panwar pro-

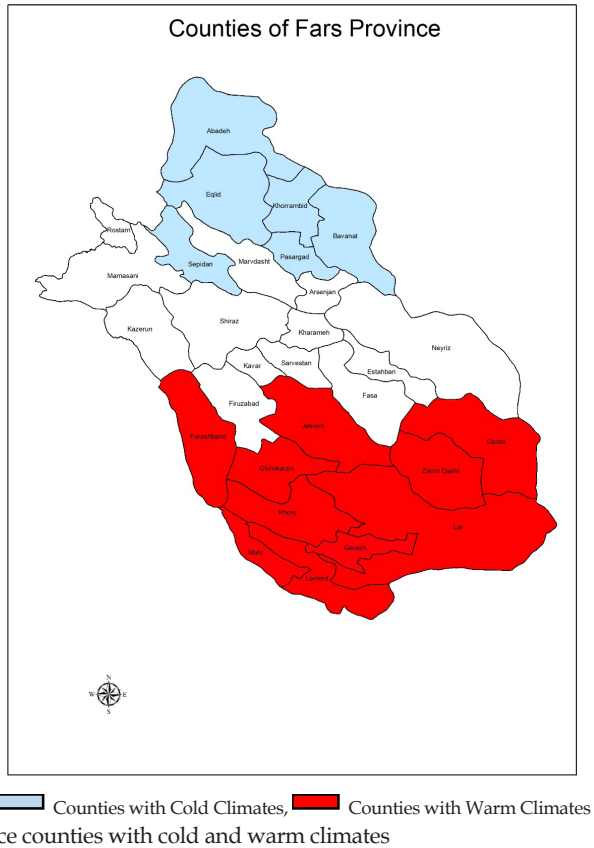

Figure 1. Location of Fars province counties with cold and warm climates

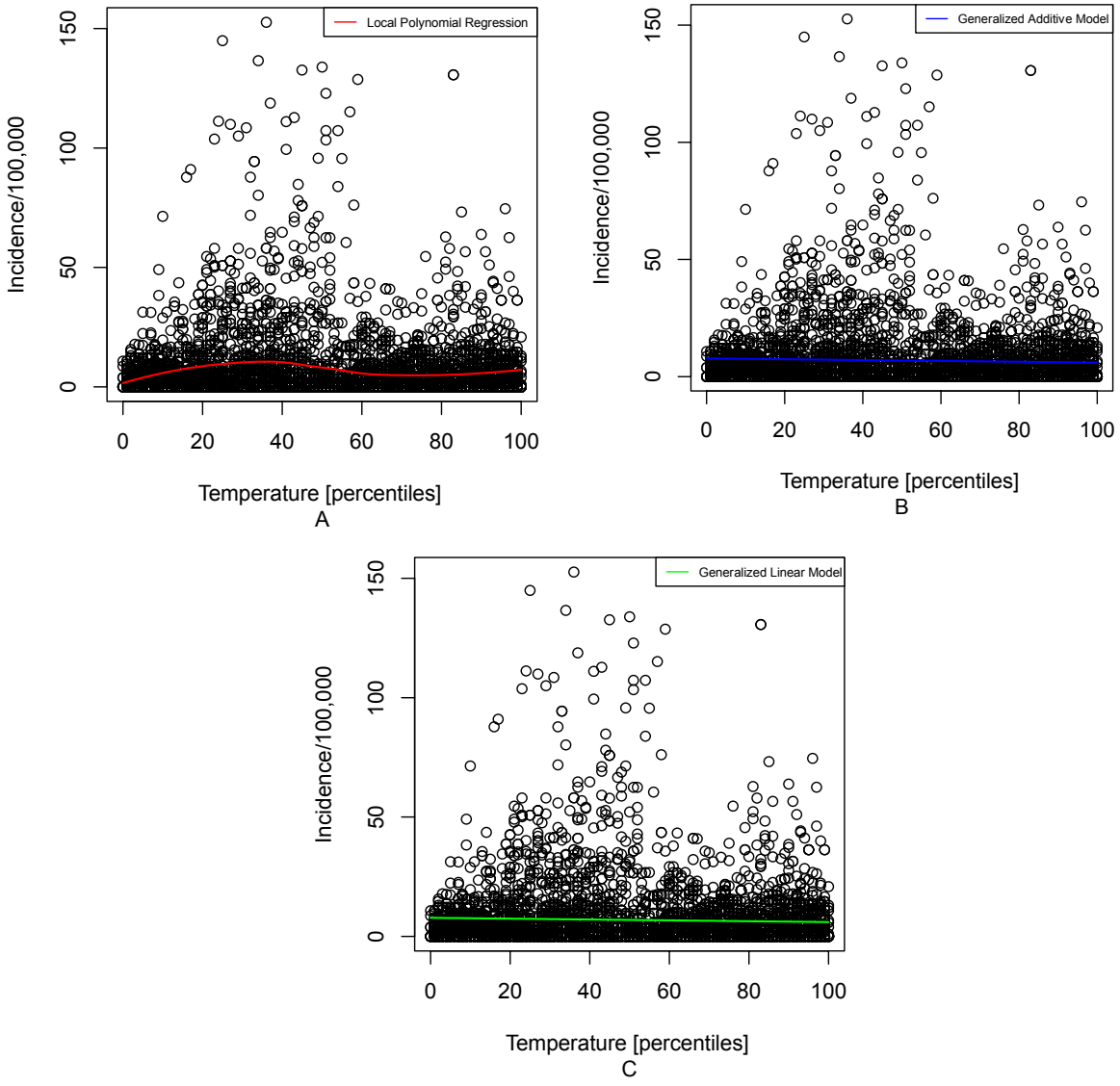

Figure 2. Assessing the distribution of COVID-19 cumulative incidence as a function of ranked percentiles of temperature

A: Distribution of COVID-19 cumulative incidence as a function of ranked percentiles of temperature by LWRs model

B: Distribution of COVID-19 cumulative incidence as a function of ranked percentiles of temperature by GAMs Model

C: Distribution of COVID-19 cumulative incidence as a function of ranked percentiles of temperature by GLMs model

posed that a cold environment may be an additional risk factor for COVID-19 cases [13]. In our study, in contrast to some research, we did not find high incidence rates at low temperatures. One explanation might be the indirect social isolation in very cold weather. Ozyigit suggested that temperature plays a slight but important role in COVID-19 transmission rates [14]. In another study, the data from 57 countries were explored for the plausible relationship between the daily average temperature and COVID-19 cases, and no association was observed. They showed that 93.5% of the confirmed COVID-19 cases occurred in temperatures between 1°C to 16°C and the average number of daily cases in countries with high temperatures was lower than in countries with low temperatures, with some exceptions [1]. Juni et al. did not find any associations between the COVID-19 pandemic growth with latitude and temperature [8]. In Iran, two similar studies suggested that high temperature does not lead to an increase in COVID-19 cases [9, 10].

Our findings led us to wonder if there are other factors besides or apart from temperature, such as good indoor ventilation. Briz-Redon et al. stated that the reports which demonstrate the impact of warm climate on the

risk of transmission of COVID-19 cannot be satisfying for controlling the pandemic. Since such studies have used data selected from small areas, a single country might be more advisable for such analysis [3]. In our study, we selected a single province that had counties with both cold and warm climates. But, we used the aggregating data model. One of the major issues with the use of aggregating data model or ecological study is the ecologic fallacy that attributes the results of aggregating data to individual subjects of the research, and the only way to deal with this issue is to conduct a longitudinal study with individual data. This is the characteristic of ecological studies and they are directed to generate a hypothesis. We hypothesized that the higher rates of disease transmission at both lower and higher temperatures might be because of the indoor gathering of people in cold and warm temperatures. Accordingly, doors and windows are closed at houses, offices, and public buildings to prevent energy waste, thereby leading to insufficient ventilation of indoor spaces. This, subsequently, leads to a higher risk of disease transmission. As it is strongly proven that sufficient ventilation in closed spaces can reduce transmission of disease [15], perhaps the temperature itself does not control the transmission of the disease and it would be rather related to the proper social response to the temperature fluctuations. However, this is just a hypothesis that needs to be further investigated.

Study limitations

The study's major limitation was the use of aggregating data and the possibility of ecological fallacy. The other limitation was concerning the lack of accounting for several major protective measures against COVID-19 transmission, including adherence to social distancing, wearing masks, and hand hygiene.

5. Conclusion

In this study, we showed that the daily COVID-19 incidence rate cannot be explained as a function of daily temperature in southern parts of Iran. Also, we found that the cumulative incidence rate of COVID-19 declined from 20°C to 25°C and 25°C to 35°C for counties with cold and warm climates, respectively. This is while outside these ranges of temperature, the incidence rate was increased, possibly because of people's indoor gatherings and insufficient ventilation of indoor spaces. Further studies with individual data are recommended to warrant the plausible confounders.

Ethical Considerations

Compliance with ethical guidelines

This research was approved by the Ethics Committee of Shiraz University of Medical Sciences (Code: IR.SUMS.REC.1399.174)..

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Authors' contributions

Conceptualization and supervision: Alireza Mirahmadizadeh, Data analysis: Alireza Heiran, Methodology: Abdolrasool Hemmati, Mehrzad Lotfi, Alireza Mirahmadizadeh, Investigation, writing – original draft: Roya Sahebi, Data collection: Mahsa Akbari, Alireza Forouzanrad, Writing – review & editing: All authors.

Conflict of interest

The authors declare no conflict of interest.

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